Terra FM-1 and FM-2 Instrument Report

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21st CERES Science Team Meeting
Hampton, VA
May 2, 2000

NASA Langley Research Center
Atmospheric Sciences

Terra FM1 & FM2 Instrument Report

Summary of what is / isn't included in 'Beta' Data Products

- Instrument Offsets, Terra and Aqua Deep Space Status
- Pre-Flight Spectral Response Functions

Status of Validation Efforts

- Ground and In-Orbit performance stability
  - Internal Calibrations (Thomas, Al hajjah)
  - Solar Calibrations (Wilson)
  - 2nd Time Constant (Pandey)
  - Navigation Accuracy (Spence)
- Inter Channel/Instrument consistency
  - Deep Convective Reflectance (Priestley, Spence)
  - 3-Channel Intercomparison (Priestley, Spence)
  - Theoretical longwave Comparison (Kratz)
  - Tropical mean: Terra/TRMM/ERBE, day/night (Green)
  - Terra/TRMM view zenith/azimuth matched comparison (Haeffelin)

Terra/CERES Mission Status

<u>Activation Timeline Summary</u>

- **Succesful launch from Vandenberg, CA on December 18, 1999**
- **Operational Power applied December 21 (Scan head remained stowed)**
- **Full time A&E operations begun in early January**
  - **Instrument level functional testing**
  - **internal calibrations (Covers Closed)**
  - **simulated solar calibrations**
- **CERES Main and MAM covers opened on February 25, 2000**
- **Intense 30-day Validation phase begins**
  - **daily-bidaily-weekly internal/solar calibrations**
  - **daily intercalibrations with the TRMM instrument (still occuring)**
  - **3-day cycle of 2-days FAPS then 1-day RAPS**
- **Nominal operations begun April 1st with FM-1 in RAPS and FM-2 in FAPS**
- **May 1st instruments shift RAPS/FAPS duties**

All major A&E activities completed except for Deep Space Maneuver….

Scan Dependent Offsets, What are they and what is their origin?

Scan dependent offsets, o, are extraneous instrument artifacts which impart sample dependent biases on the radiometric measurements.

Typically arise from one of two sources:

1. Electromagnetic signals
   These signals are picked up as the sensor rotates through dynamic emf fields which surround the high voltage electronic circuitry
2. Micro-strains
   Thermistor bolometers act as strain gauges and rotating the sensor modules can impart micro-strains on the detectors.

Magnitude is typically a function of 6 parameters, the angular position, scan rate, and acceleration rate of the sensor about both the elevation (ε) and azimuthal (α) axes,

$$o = F(\varepsilon, \dot{\varepsilon}, \ddot{\varepsilon}, \alpha, \dot{\alpha}, \ddot{\alpha})$$

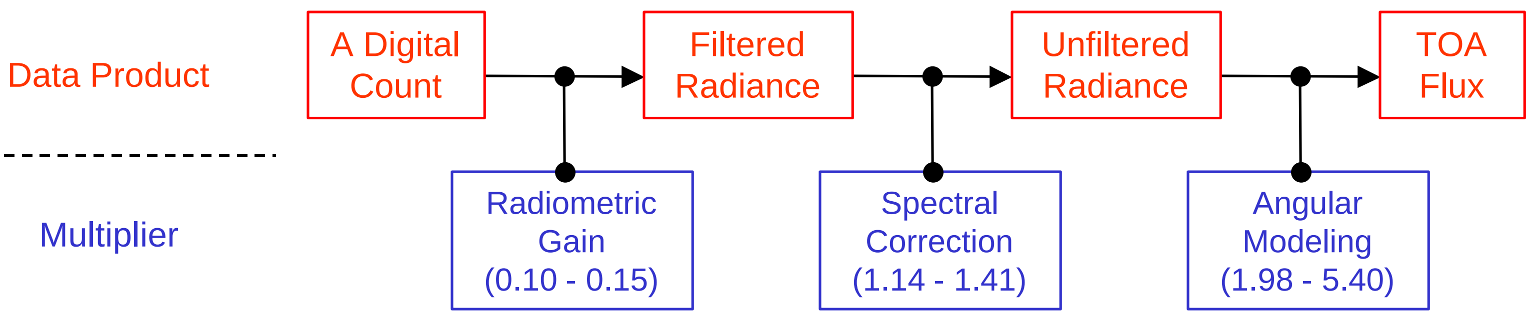
How significant are they?

Mission accuracy requirements are 0.5% for Longwave 1.0% for Shortwave, or

1.2 W/m^2 TOA LW Flux

2.0 W/m^2 TOA SW Flux

Accurate knowledge of scan dependent offsets at the sub 1-count level is necessary to meet this objective. The relationship between a digital count and TOA Flux is…..



SW : 1 count ~0.50 W/m^2 TOA Flux

LW $_{NIGHT}$: 1 count ~0.55 W/m^2 TOA Flux

→ LW $_{DAY}$: 1 count ~1.05 W/m^2 TOA Flux ←

LW $_{DAY}$ = Total - Shortwave

Therefore, the Total and Shortwave offsets are roughly additive in the worst case.

TRMM Lessons Learned

- **Ground to on-orbit shifts of approximately 1 count peak-to-peak occurred in all three channels of the CERES PFM instrument.**
  - Shifts were not systematic among the channels
  - Total and Shortwave channels shifted in opposite directions
- **Analyses of the collected data indicates that 30-50 repetitions of each combination of elevation and azimuthal angle are necesary.**
- **CERES/TRMM scan dependent offsets have been reduced an order of magnitude from ERBE.**

<u>Bottom Line</u>

- **A significant improvement made over ERBE**
- **CERES Accuracy requirements are a factor of 2 more stringent than ERBE**
- **Offsets are still significant as potential error sources for CERES**
- **TRMM should only be viewed as a 'best case' until the design is validated over several flight models**

Impact of Terra/Aqua Omitting/Delaying CAM's

Immediate

- **Traceability to ground calibration radiometric scale less certain**
- **Significant impact on validation timeline for the Level-1 data**
  - this would then impact all downstream data products ERBE-like, TISA, SSF etc.
- **Could force unnecessary reprocessing**
- **Intercalibration with other Earth Radiation Budget instruments less certain**

Long Term

Accurate and useful monitoring of the Global climate requires instruments that very accurately measure small perturbations about a relatively large mean value.

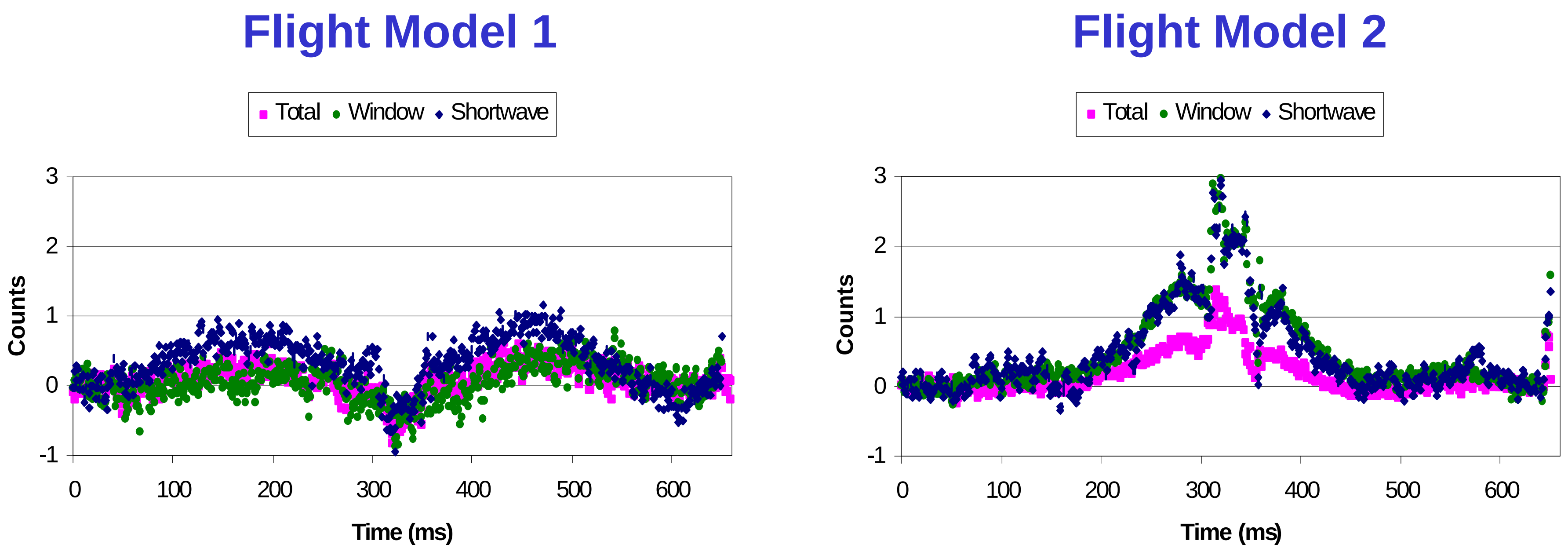
- **Ability to detect climate change would be limited. An instantaneous doubling of atmospheric CO_2 would produce a temporary change in TOA flux of ~4 W/m^2.**
- **Apparent change in OLR from ERBE to CERES of ~4W/m^2 on decadal scale.**
- **TRMM radiometric stability - no detectable change at 0.25% (95% confidence)**

- **Voltage converters replaced - need to verify no Impact on offsets**
- **Detectable change in baseline electronic noise on FM-1. First noticed subsequent to spacecraft level environmental testing.**

CERES Terra Scan Dependent Offsets

Ground Derived Values

(Fixed Azimuth Plane Scan mode)



SW : 1 count ~0.50 W/m^2 TOA Flux

LW $_{NIGHT}$: 1 count ~0.55 W/m^2 TOA Flux

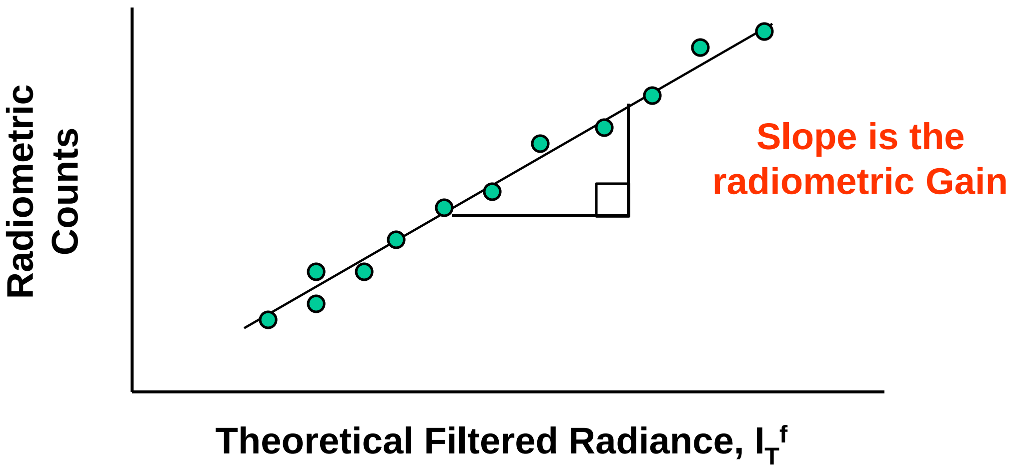
LW $_{DAY}$: 1 count ~1.05 W/m^2 TOA Flux

For all CERES 'Beta' data products the scan dependent offsets are assigned values of zero.

Longwave Spectral Characterization

(2.5 - > 100 μm)

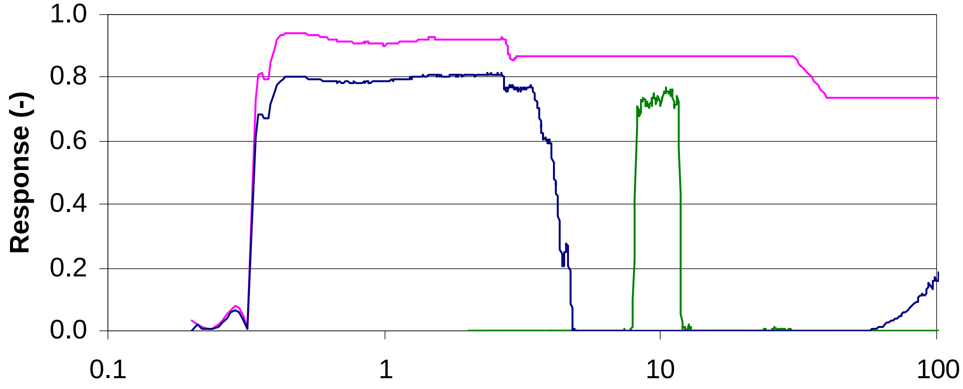
Regressing sensor output (radiometric counts) as a function of theoretical filtered radiance, I_T^f, for each of the 12 calibration NFBB temperatures over the range of 205 to 315K yields



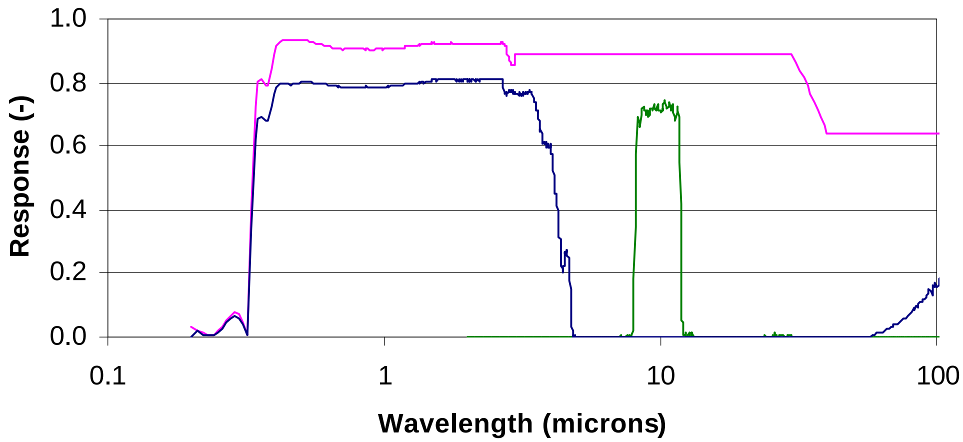
- **The final LW spectral response, S_λ, is determined by optimizing this regression**
- **By optimizing we mean adjusting the estimate of S_λ within the understood FTS measurement uncertainty such that the residuals in the regression are minimized.**
- **This methodology ensures that CERES is optimally calibrated against longwave radiance sources that have Planck like spectral distributions.**

CERES Flight Models 1 & 2
PreFlight Spectral Response Functions

Flight Model 1

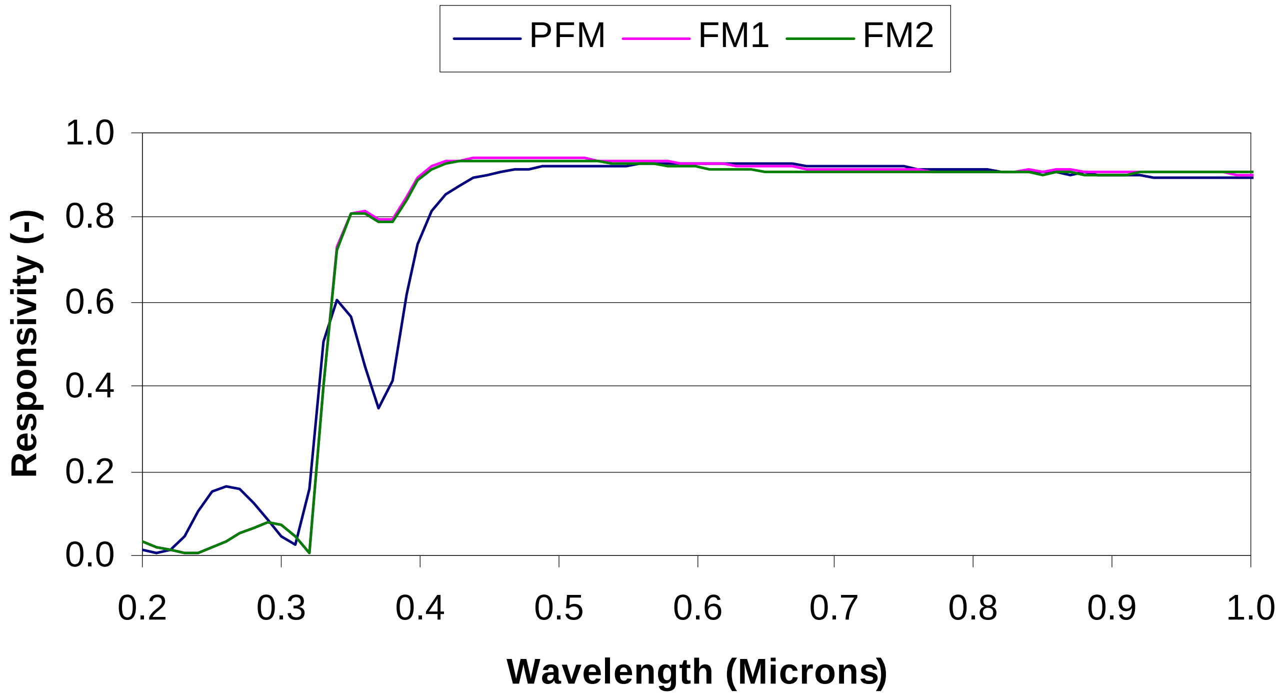


Flight Model 2



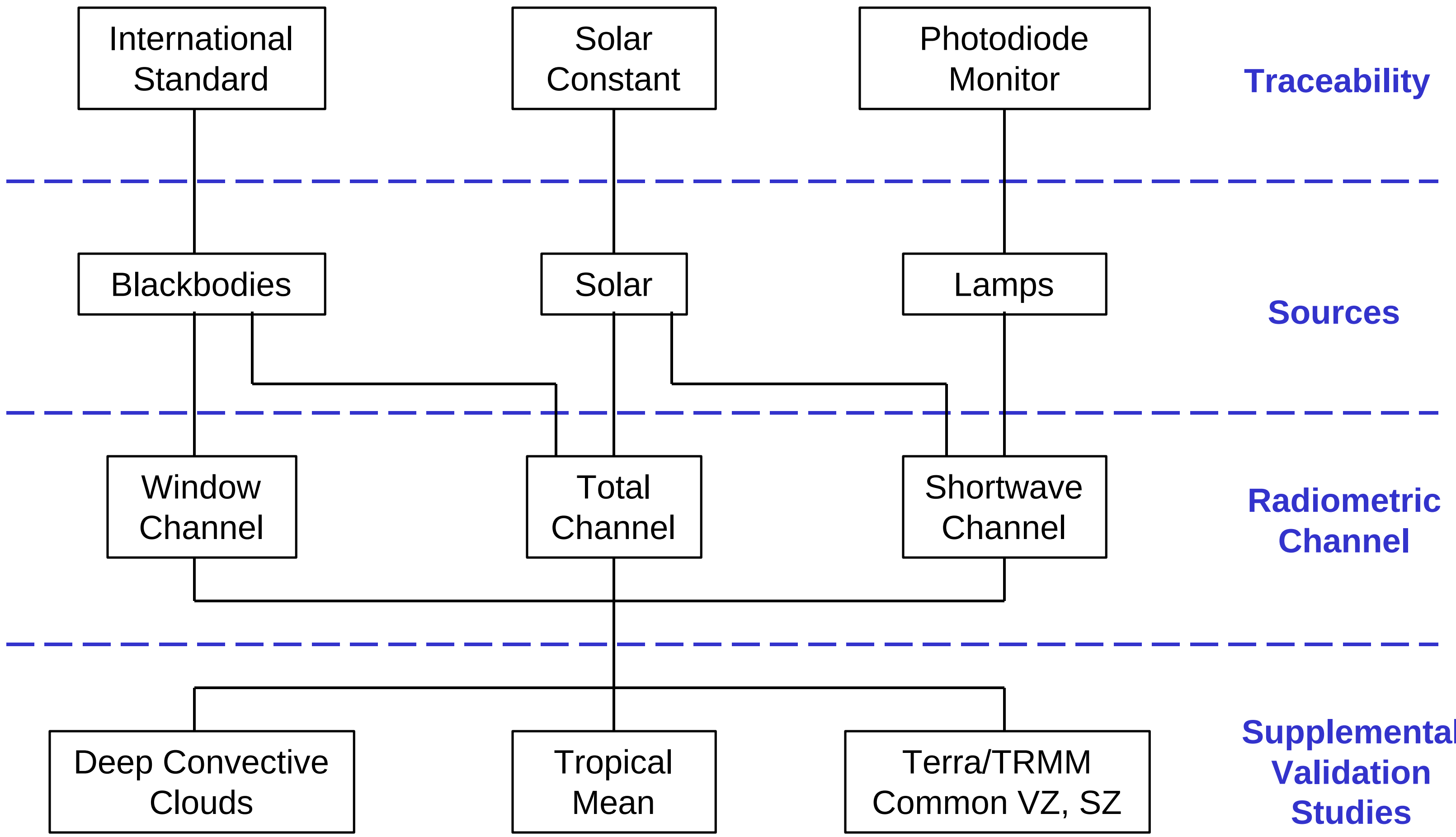
These PreFlight Spectral Response Functions are Used in the 'Beta' Erbe-like data products

SW Spectral Response Function Comparison of PFM to FM1 and FM2



Flight Models 1&2 transmit considerably more energy between 0.3 to 0.5 microns compared to PFM

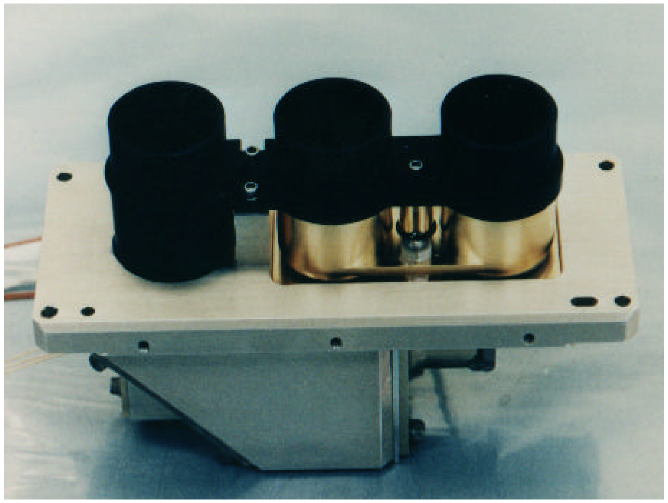
CERES On-orbit Calibration Philosophy

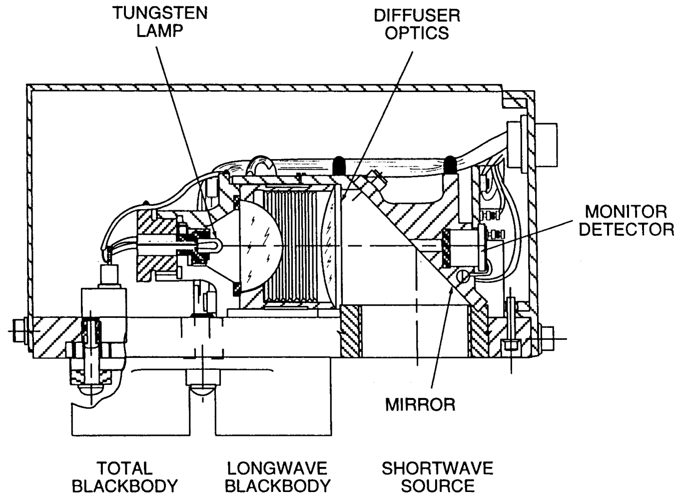


CERES Onboard Calibration Sources

Internal Calibration Module (ICM)

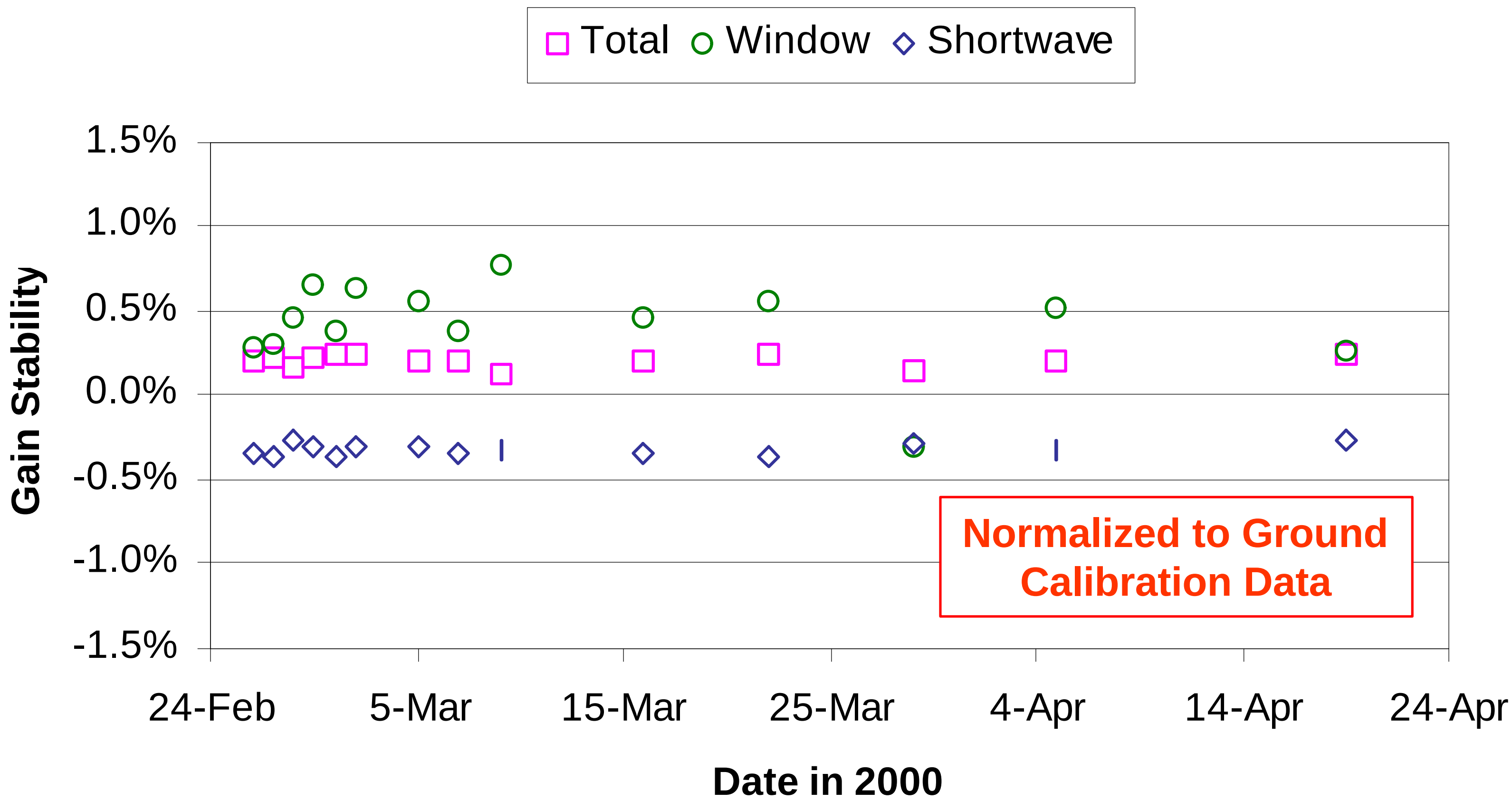
- Blackbodies for the Total and Window channels
- Temperature knowledge obtained via Platinum Resistance Thermometers (PRTs)
- Quartz-halogen tungsten lamp for the Shortwave channel
- ICM Provides 3 unique radiance levels for the SW and LW sources





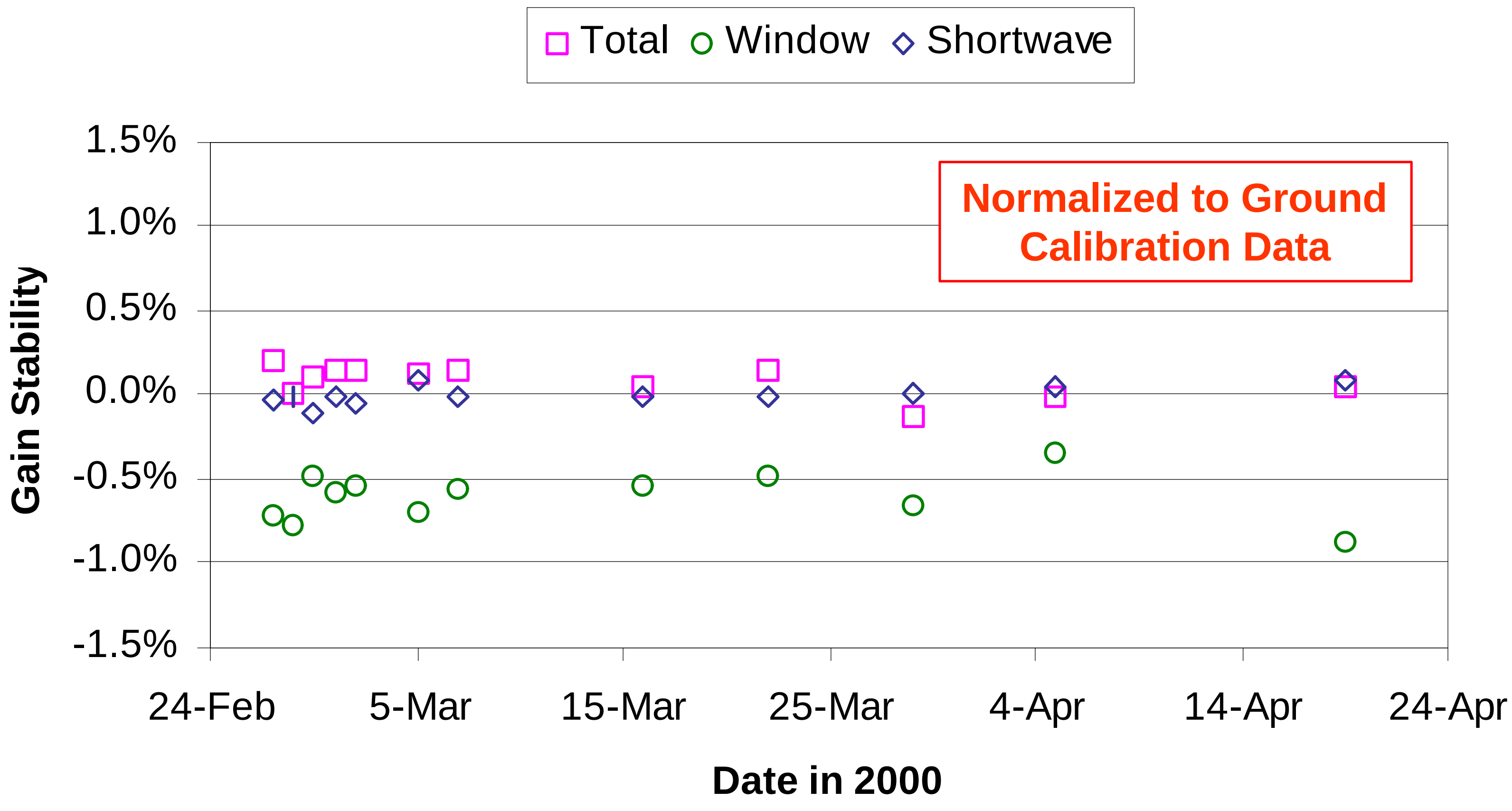
Terra/Flight Model 1
Lifetime Radiometric Stability

Determined with the Internal Calibration Module



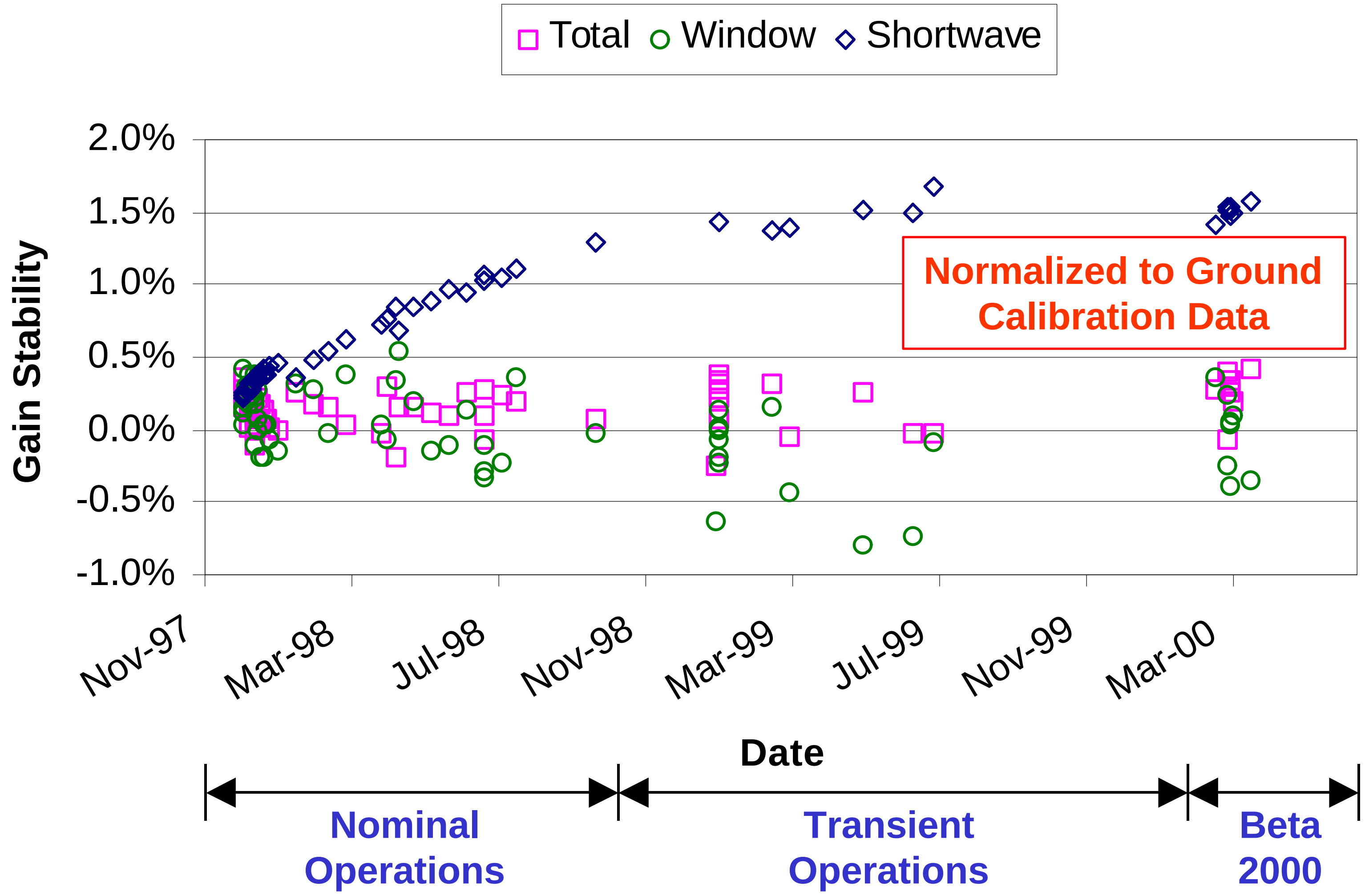
Terra/Flight Model 2
Lifetime Radiometric Stability

Determined with the Internal Calibration Module



TRMM/Proto Flight Model Lifetime Radiometric Stability

Determined with the Internal Calibration Module



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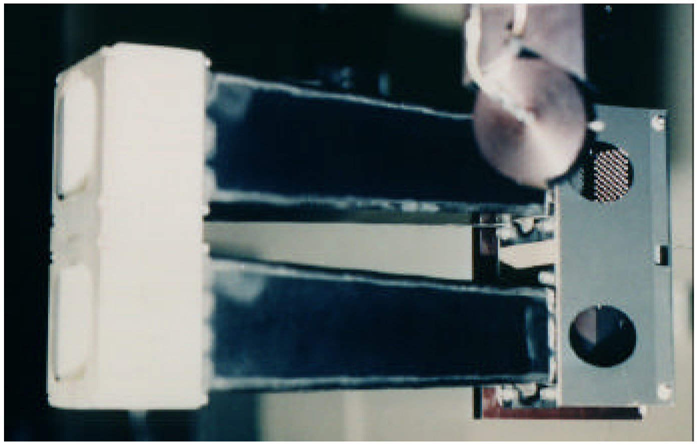
Atmospheric Sciences

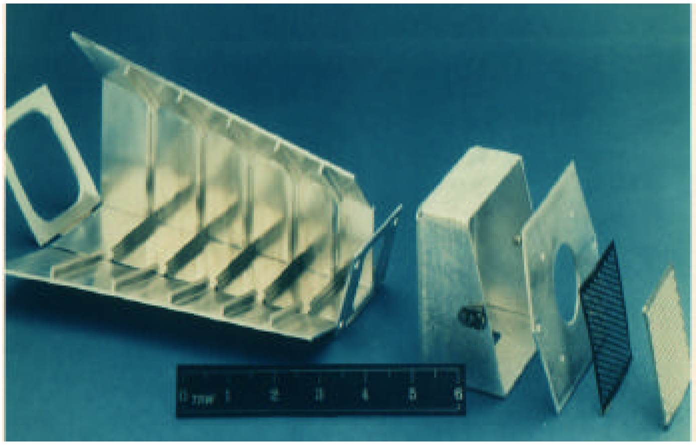
K. J. Priestley 11/3/98

CERES Solar Calibration

Mirror Attenuator Mosaic

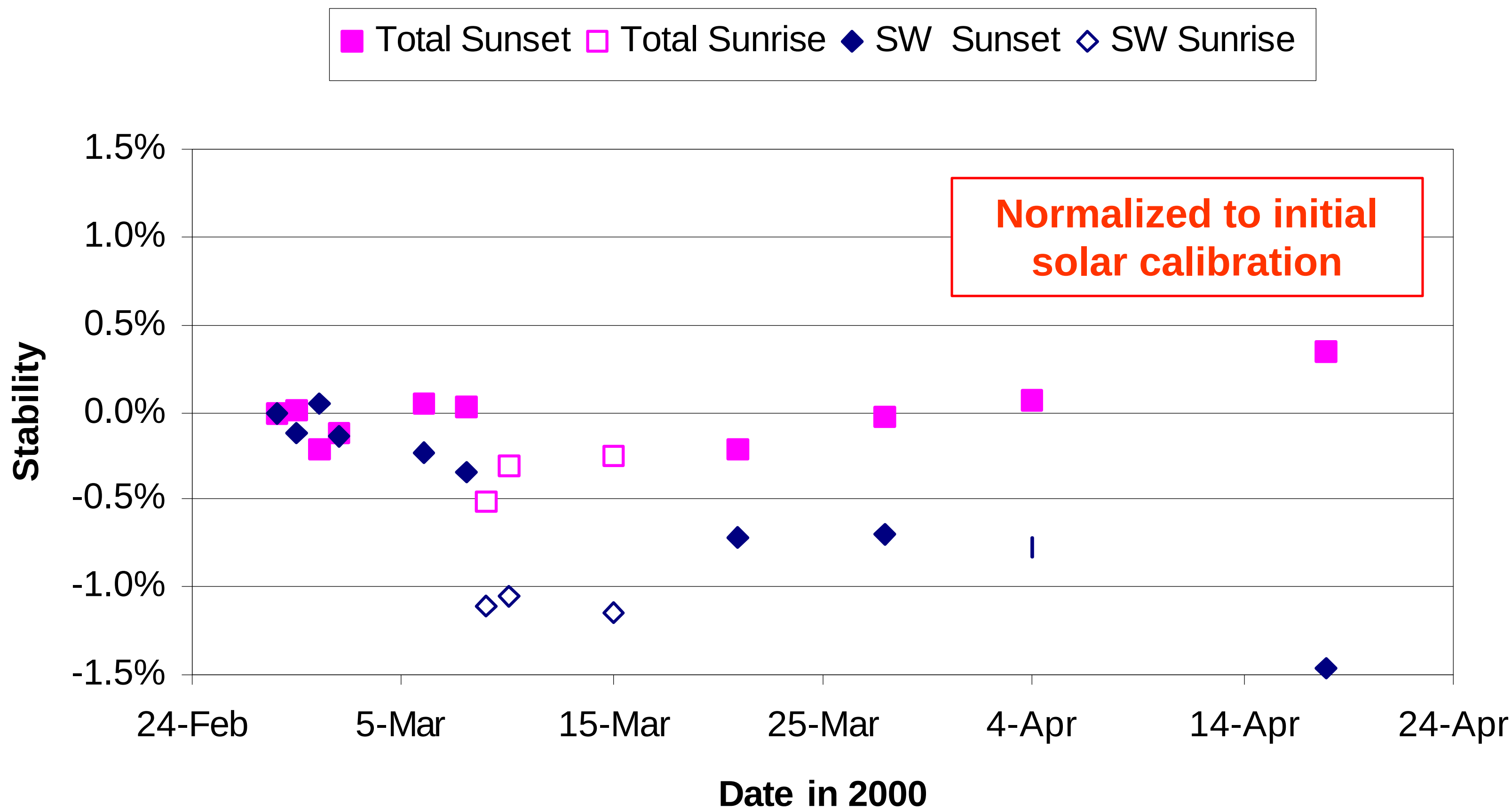
- The MAM is a Solar Diffuser plate which attenuates direct solar view
- Fabricated from a Nickel substrate with Aluminum coated spherical cavities or divots
- Forward baffles limit Field-of-View to ± 4-degrees, prohibiting stray light contamination
- Provides a Relative calibration of the Shortwave channel and the SW portion of the Total channel





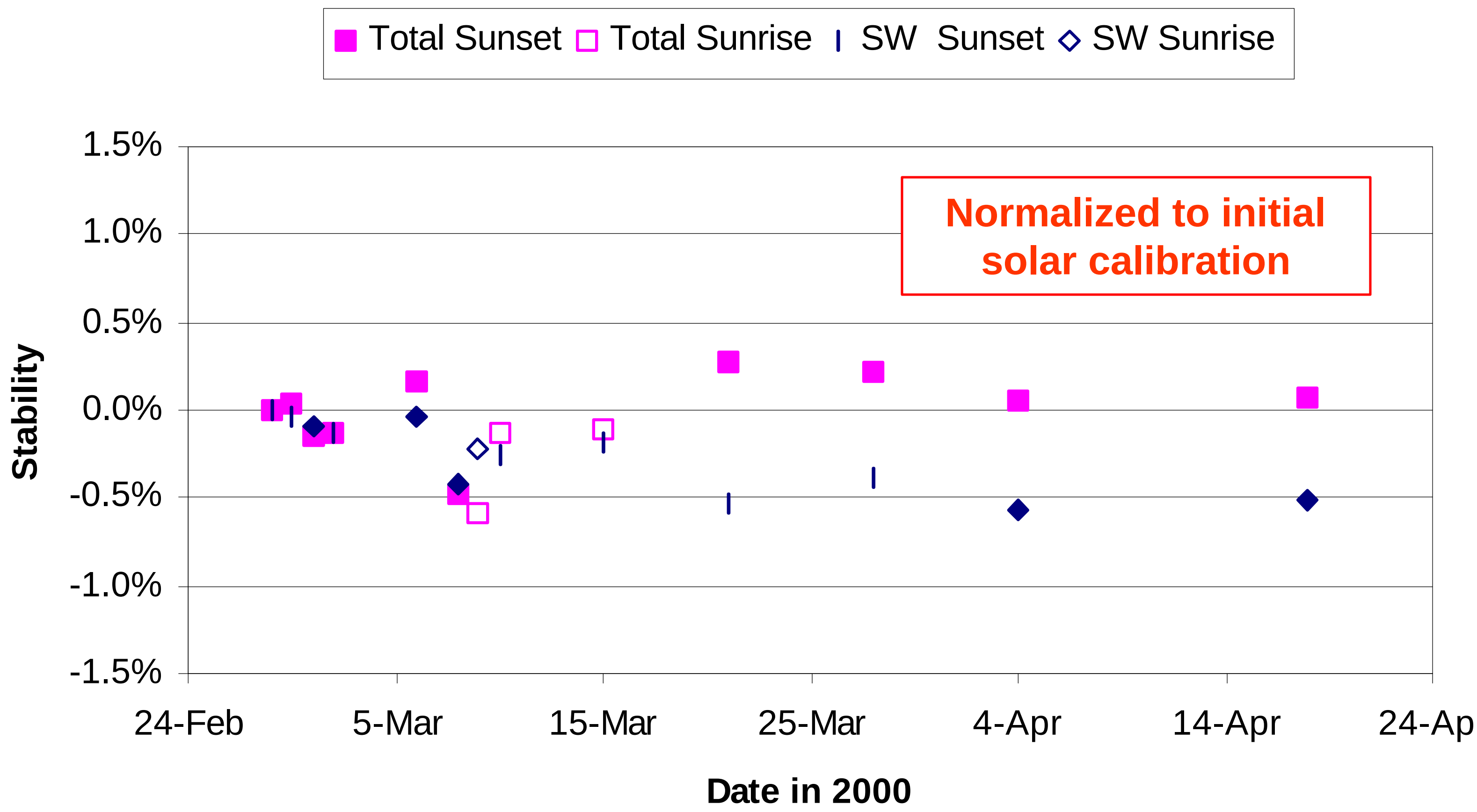
Terra/Flight Model 1
On-orbit Shortwave Radiometric Stability

Solar Calibrations Performed with the Mirror Attenuator Mosaic



Terra/Flight Model 2
On-orbit Shortwave Radiometric Stability

Solar Calibrations Performed with the Mirror Attenuator Mosaic



Instrument Slow Mode Response Pre-flight Coefficients

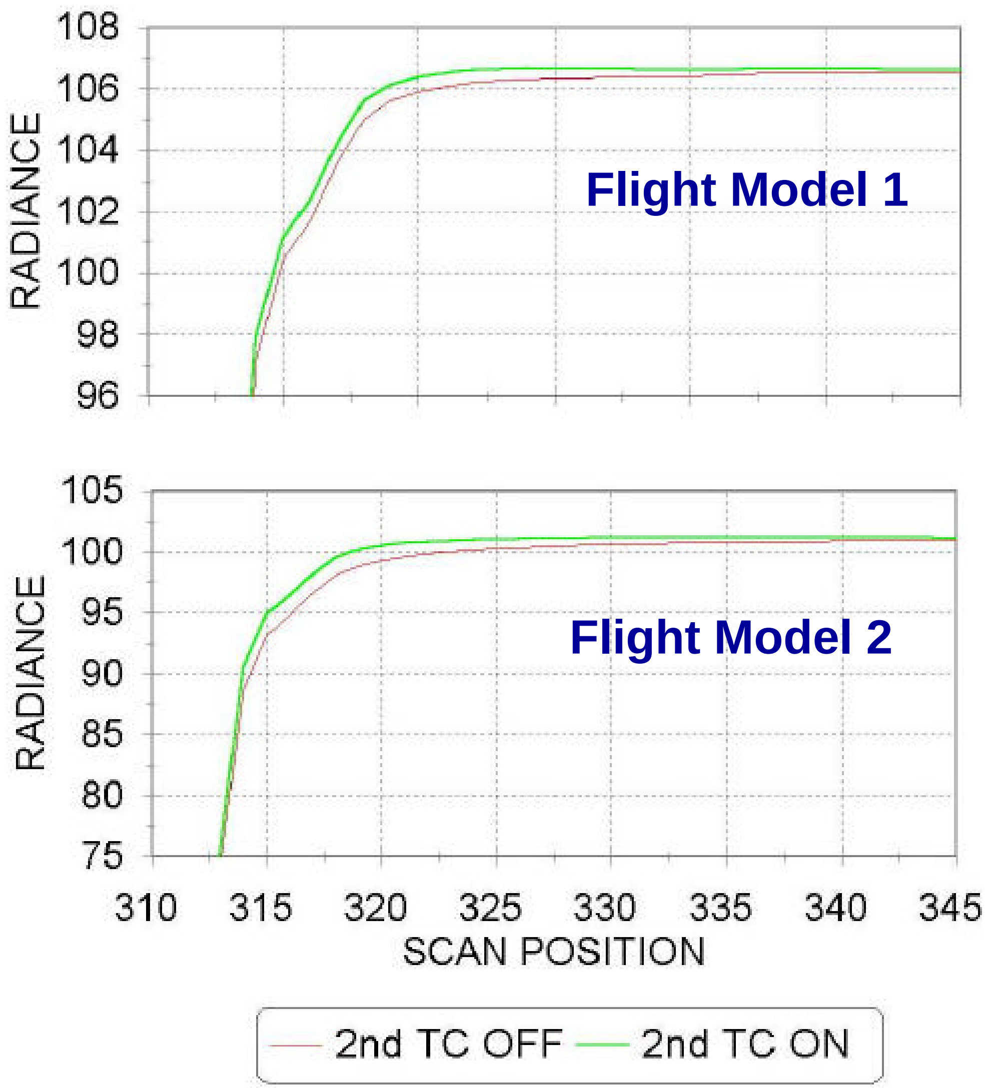
Flight Model	Channel	$1/\lambda$ (sec)	C (%)
FM1	TOT	.107	1.0
	WN	.215	1.4
	SW	.342	1.6
FM2	TOT	.106	2.6
	WN	.177	1.2
	SW	.122	2.3

On-orbit validation sequences have not yet been executed.

Production code is currently using pre-flight derived values.

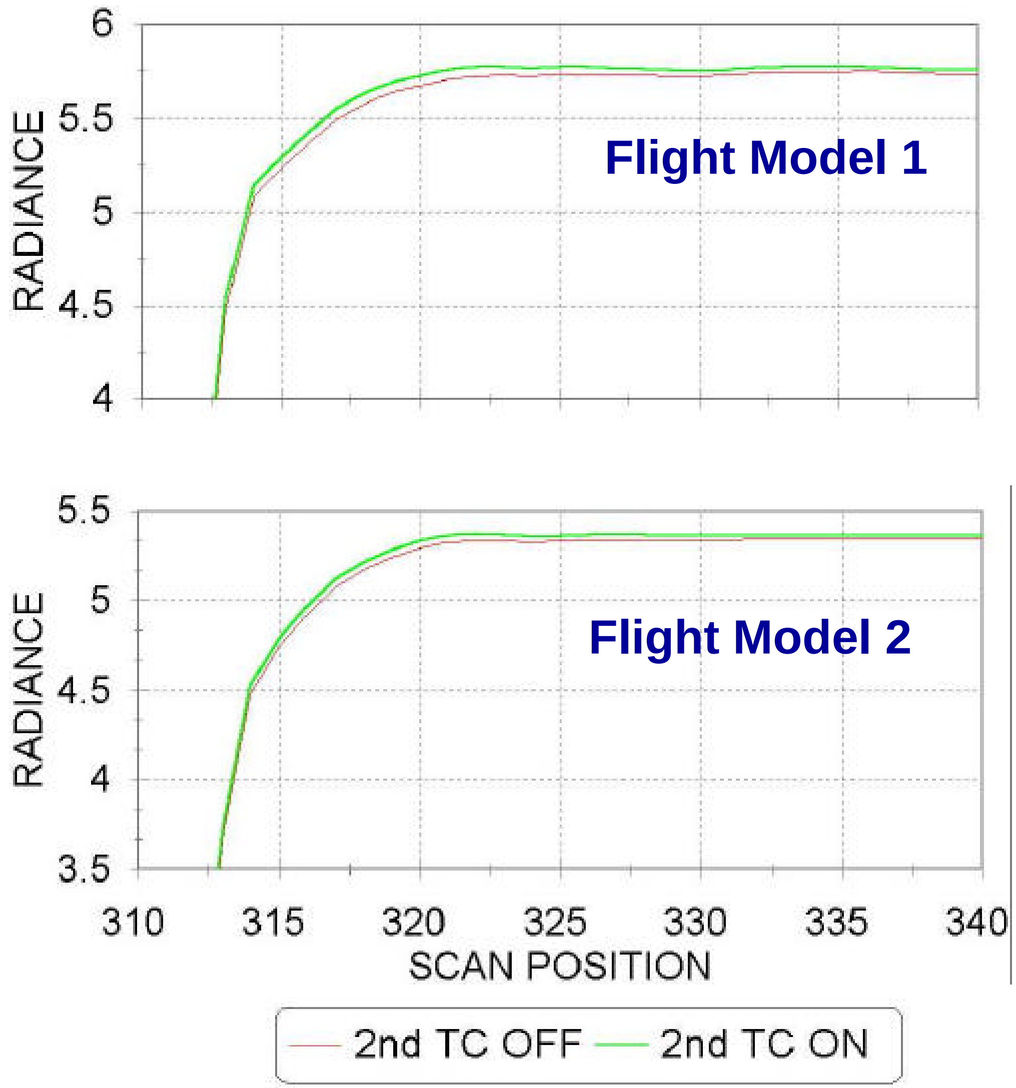
Slow Mode Removal Qualitative Results

Total Channels scanning onto Internal Blackbodies (Daily Averages for 3/29/00)



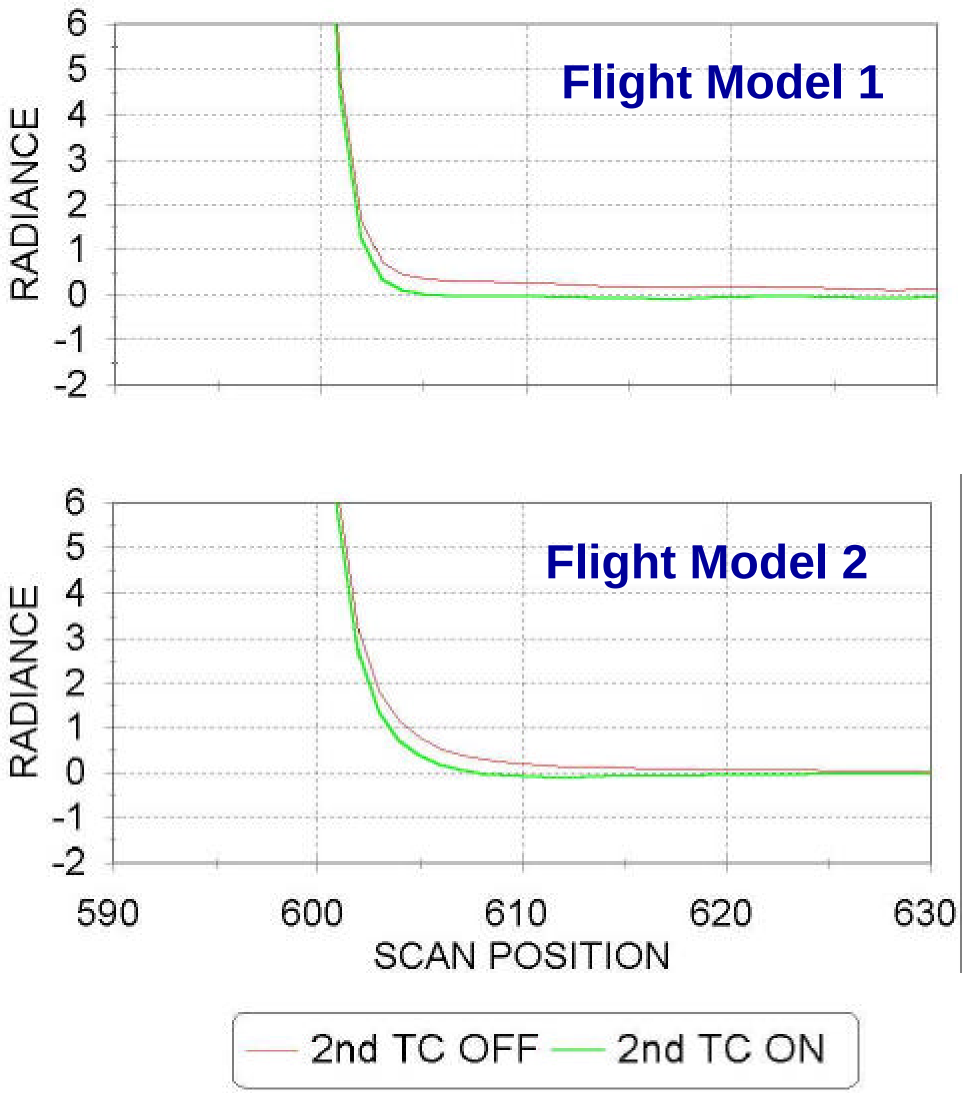
Slow Mode Removal Qualitative Results

Window Channels scanning onto Internal Blackbodies
(Daily Averages for 3/29/00)



Slow Mode Removal Qualitative Results

Shortwave Channels scanning off of the Earth
(Daily Averages for 3/29/00)



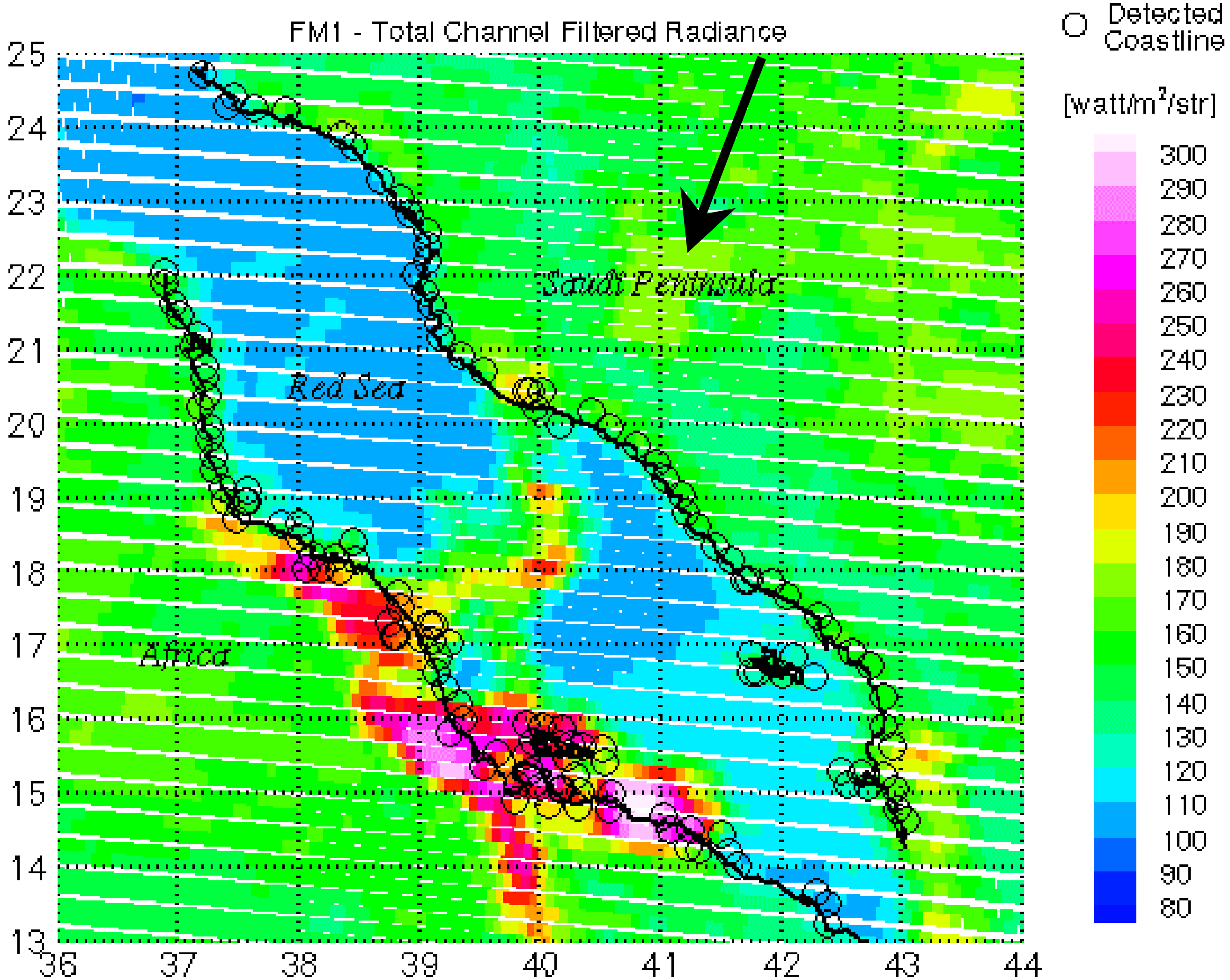
Navigation Accuracy
Automated Coastline Detection

Status

- Automated system uses the Total channel to detect coastlines
- Analysis completed for 20 FM1, and 18 FM2 scenes occurring February 28, 2000
- <1km mean navigational errors for both instruments in both along-track and cross-track directions
- Additional days need to be analyzed to improve statistics/monitor performance

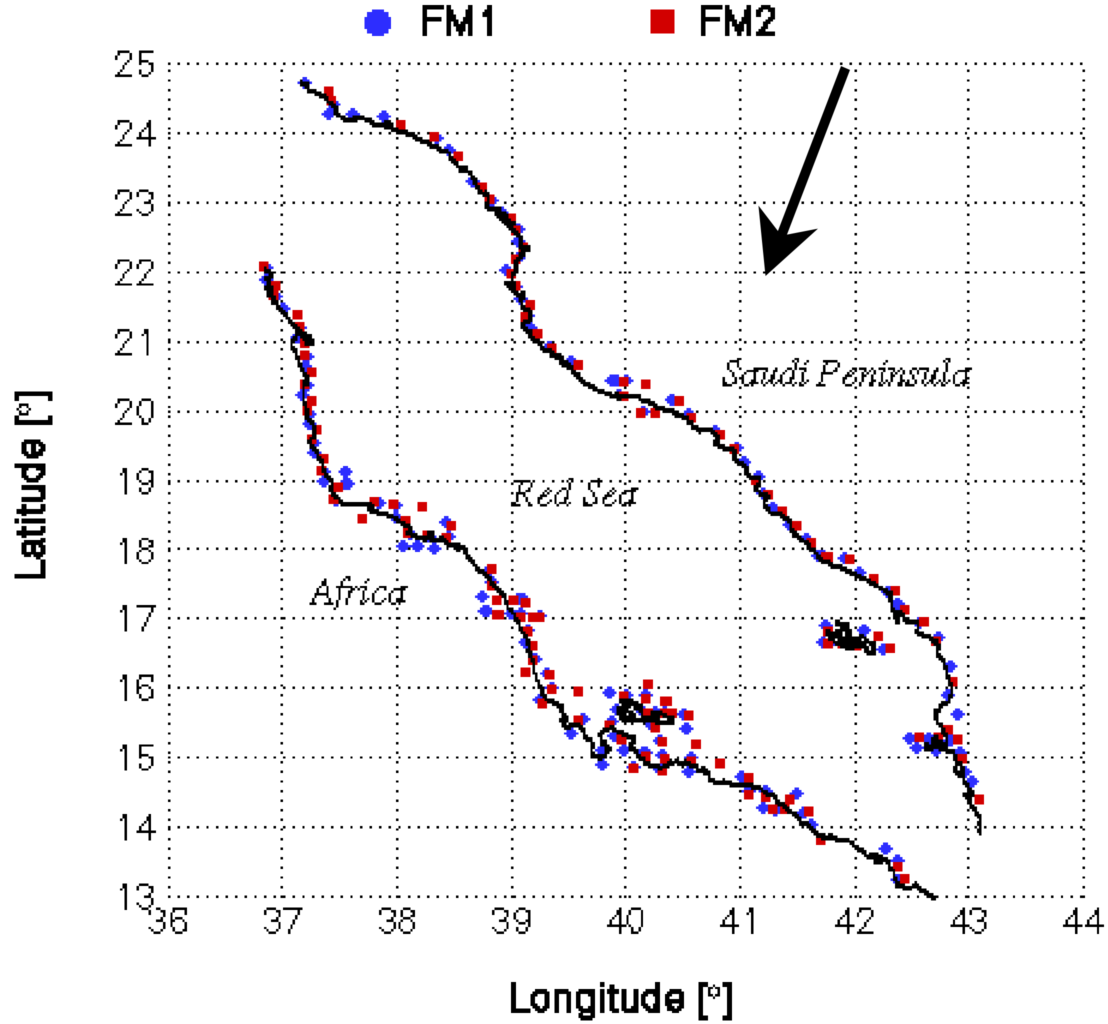
Terra/CERES Coastline Detection

28 February 2000, Descending, 08:10:00 - 08:20:00 UT



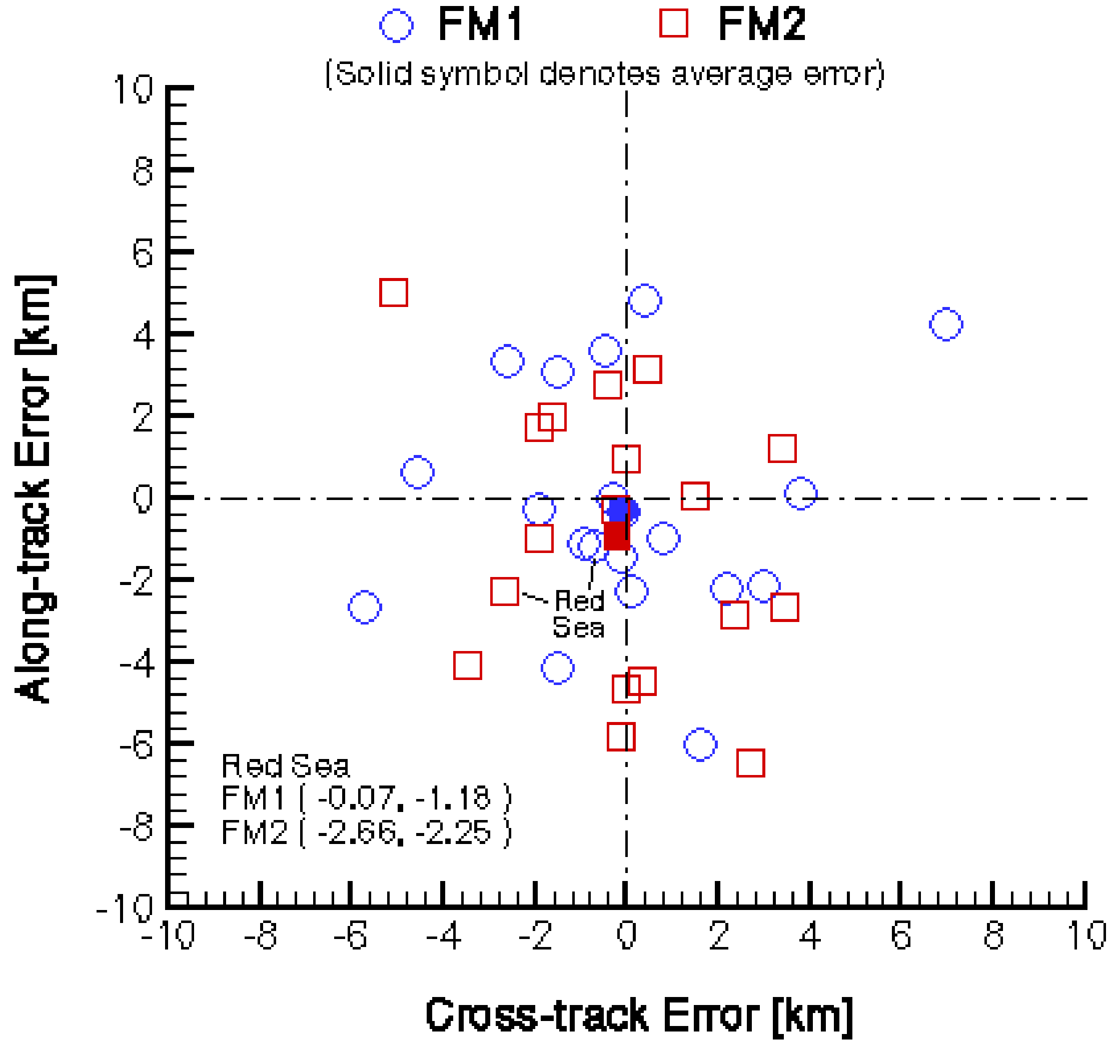
Terra/CERES Coastline Detection

28 February 2000, 20 km Square Search



Terra/CERES Coastline Detection

28 February 2000, Error Analysis



CERES Deep Convective Albedo, March 2000

We have calculated the isotropic albedo, or reflectance, R, for Tropical Deep Convective Clouds as defined by

$$R = \frac{\pi I}{E_o d^{-2} \cos\theta_o}$$

The goal is to intercompare the three CERES instruments.

DATASET

Scene Type: Independent Deep Convective Cloud systems

Cloud Size: Greater than 20 Km in ground track direction

Cloud Temperature: Less than 215 K (Dispersion <0.1)

Data Product: CERES PFM, FM1 and FM2 (March 2000)

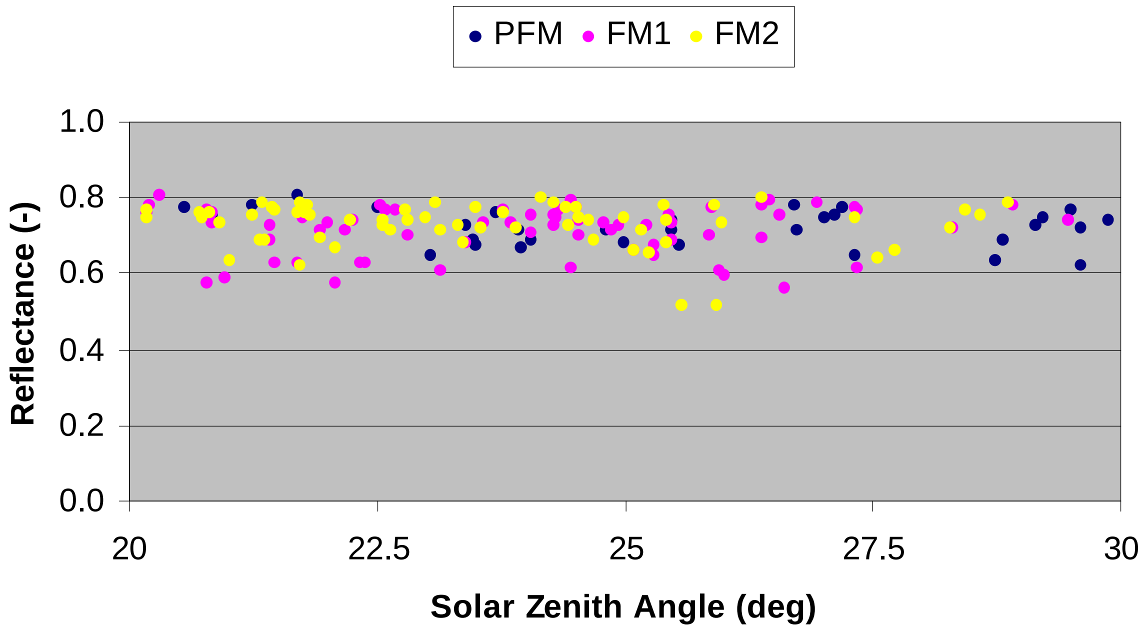
View Zenith: Nadir footprints only

Solar Zenith: 20 to 30-degrees (Limited by Terra Orbit)

Latitude: 20 N to 20 S

CERES Deep Convective Albedo, March 2000

Results of estimating reflectance over the solar zenith range of 20-30 degrees. The relative uncertainty in each measurement is in parentheses.



	PFM	FM1	FM2
Reflectance (Std. Error)	**.7212 (.85%)**	**.7148 (.78%)**	**.7301 (.73%)**

No Statistically Significant Differences

3-Channel Deep Convection Results

Assess the agreement between our best estimates of the unfiltering of the SW channel and the SW portion of the Total Channel.

With this method we cannot distinguish between errors in the spectral response function and relative errors in the spectral unfiltering method.

DATASET

Scene Type: **Deep convective clouds**

Cloud Size: **Greater than 80 Km in ground track direction**

Cloud Temperature: **Less than 215K**

Data Product: **Terra FM-1 and FM-2 'Beta' BDS files**

View Zenith: **Nadir footprints only**

Solar Zenith: **Less than 80-degrees (PFM), 19 - 31 degrees (FM 1 & 2)**

Latitude: **20 N to 20 S**

3-Channel Intercomparison

Methodology

- **Regress Filtered Window against Unfiltered Total (i.e. LW) radiances at night.**
- **Predict daytime LW with two methods…**

$$LW_{day} = Total_{day} - SW_{day} \qquad\qquad LW_{day} = C_1 * WN_{day} + C_2$$

- **Difference these two estimates and plot as a function of Filtered SW, I_f^{sw}.**

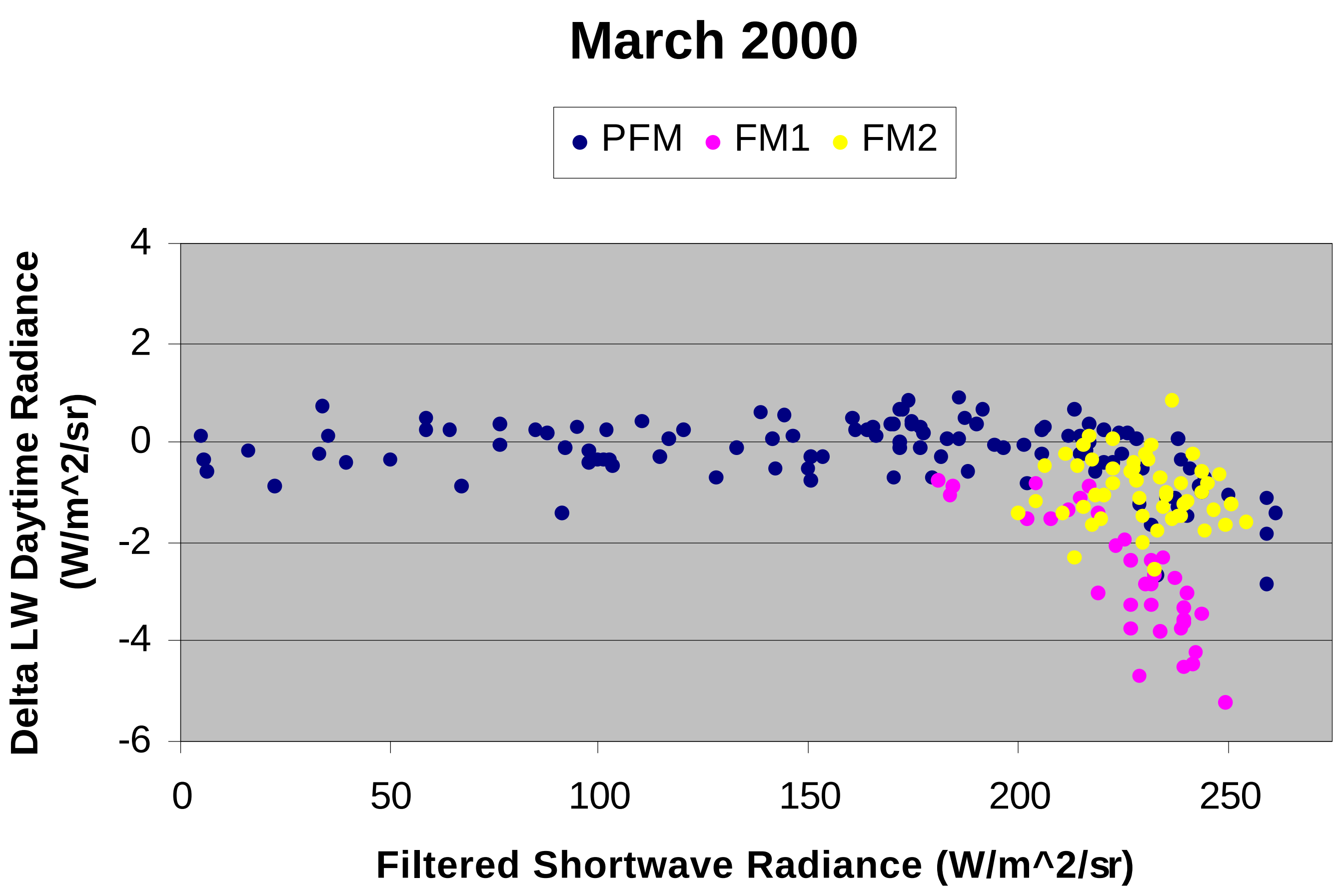
$$\Delta LW_{day} = (Total_{day} - SW_{day}) - (C_1 * WN_{day} + C_2)$$

- **Any error in the unfiltering process (either due to errors in S_λ, or in detemining the unfiltering coefficients) may be represented by**

$$error = -\frac{\left(\frac{d\Delta}{dI_f^{sw}}\right)}{\hat{a}^{lw/tot}\left(\frac{\hat{a}^{sw}}{\hat{a}^{sw/tot}}\right)} * 100$$

- **where the ’s are the spectral unfiltering coefficients for the longwave channel (lw), shortwave channel (sw) and the shortwave portion of the total channel (sw/tot) for DCC.**

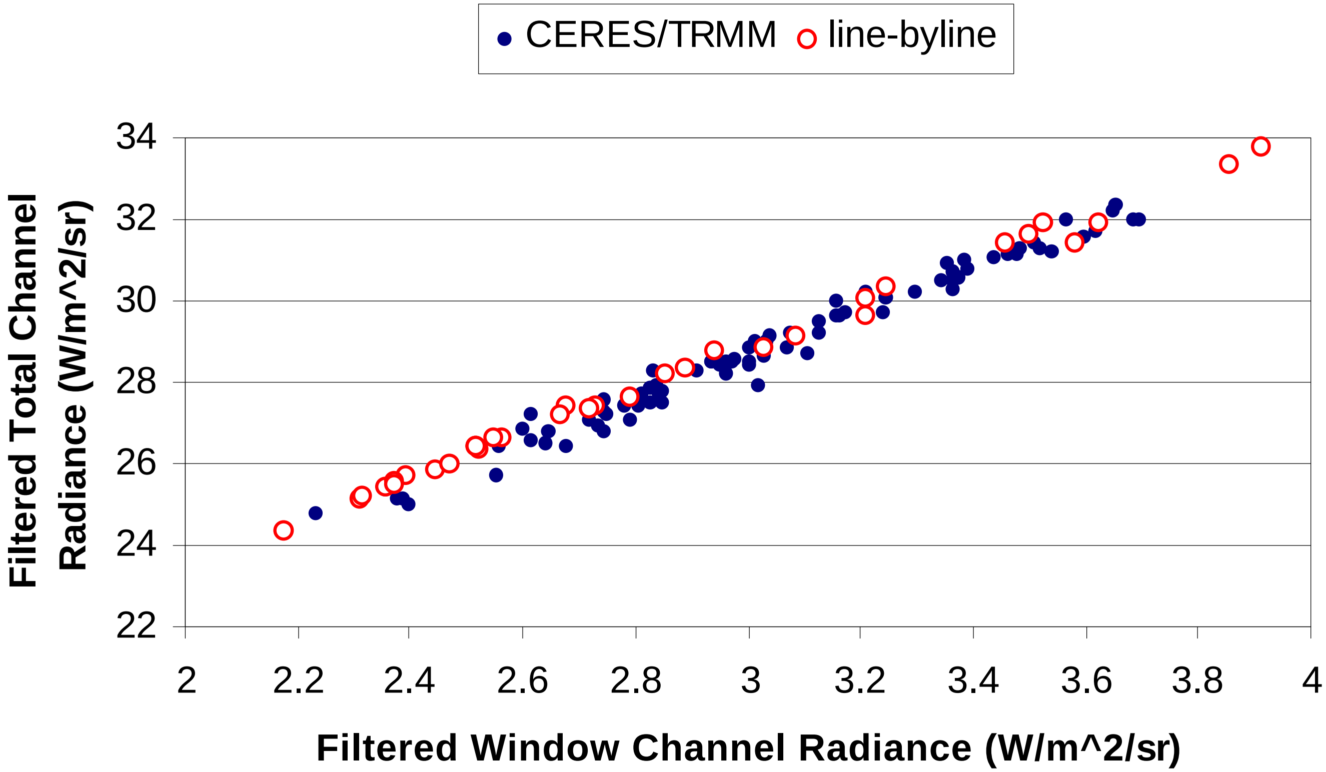
3-Channel Deep Convection Results



FM1 appears to demonstrate a significant inconsistency between the SW channel and SW/TOT channel

Line by Line Radiative Transfer Code Comparison

CERES on TRMM
Nighttime Deep Convective Cloud Data
Final Edition 2



Terra Instrument Report Summary

To date the Terra Instruments have performed exceptionally well….

- **Preliminary Ground to Flight Radiometric Stability**
  - Total Channels: FM1 +0.25%, FM2 <0.10%
  - Window Channels: FM1 +0.50%, FM2 -0.50%
  - Shortwave Channels: FM1 -0.40%, FM2 <0.10%
- **2nd-Time Constant**
  - Pre-flight algorithm coefficients appear reasonable
  - On-orbit Maneuver to be completed in early May 2000
- **Navigation Accuracy**
  - Coast Line detection Algorithm shows accuracies of better than 1 km
- **Deep Convective Albedo Results**
  - No significant differences for PFM, FM1 and FM2 SW at the ~1% level

Terra Instrument Report Summary

- **3 Channel Intercomparison**
  - Apparent small inconsistency (~1%) in the FM1 SW calibration (suspect Total channel)
- **Theoretical Longwave Comparison**
  - Not yet completed for Terra
- **Tropical Mean Terra/TRMM/ERBE day/night**
  - Nighttime consistency at 0.50% level for all three instruments (agrees with ERBS)
  - SW consistency at 0.10% level for FM1 & FM2
  - FM2 Window > FM1 Window by 0.70%, (Consistent with internal cals)
  - Nighttime FM1/FM2 differences consistent with ground offsets
  - Imbalance between FM-1 SW/TOT and LW/TOT Total channel of approximately 0.40%

TRMM PFM Instrument Report

Returned to Service February 24, 2000

Kory J. Priestley

CERES Project Office, TRMM FOT, Instrument Subsystem 1, TRW, Jim Donaldson, Jim Kibler

21st CERES Science Team Meeting

Hampton, VA

May 2, 2000

CERES/TRMM Return to Service

(or, how I have spent the last two months of my life…)

Original scenario was to power PFM back on in mid-March. However…..

- **Subsequent to meeting with the TRMM FOT on February 24th to plan a mid March power up scenario, I stopped by the Terra Mission operations Center.**
- **The Mayon volcano had just erupted in the Phillipines and Terra was anxious to get their first images. (CERES was to open covers on Feb. 25th)**
- **I phoned Bruce B. and in the excitement we decided to get PFM back on as soon as feasible**
- **2 hours later PFM was up and running.**
- **24 hours later the constellation of CERES instruments were taking world class Earth Radiation Budget measurements.**

Original scenario had PFM functioning nominally so we could focus on Terra. However…...

Saturday Morning I got a phone call….

PFM Azimuth Rotation Stickiness

- On Saturday, February 26th the TRMM spacecraft performed a nominal orbit adjustment maneuver (2 Delta V burns). These are done every 3-10 days.
- The CERES instrument was commanded to the contamination safe mode and the azimuth rotated from the crosstrack position (180-deg) to the Spare B position (165-deg).
- 11 minutes after the first burn was completed the TRMM Flight Software automatically commanded the CERES instrument back to the crosstrack position. Excessive friction in the bearing triggered a stall threshold.
- A review of the housekeeping data demonstrated that the azimuth bearing initially moved towards the 180-deg position however the bearing motor shut itself down when the actual bearing angular position lagged the 'commanded to' position by more than 2-deg for longer than 0.1 seconds.
- This was not a 'hard' stall. The azimuth bearing was not prevented from moving, only prevented from moving at the rate it was commanded to. (i.e. it was sluggish)
- A third attempt to command the azimuth bearing back to crosstrack was successful.

PFM Azimuth Rotation Stickiness Recovery and Characterization

Not exercising the bearing for 6 months allowed for some unknown change in the bearing mechanical/lubricant characteristics.

Recovery/Characterization Plan

- **Plan consists of a repeating 2-day cycle**
  - Day 1: Rotate over a defined azimuth range for approximately 15 minutes during a real time pass. Review diagnostic data collected. If it looks acceptable proceed to day 2.
  - Day 2: Rotate over the same azimuth range for approximately 90 minutes. Review diagnostic data collected. If it looks acceptable increase azimuth range by 10-deg in both directions and repeat Day 1.
- **Continue cycling until the full azimuth range of 90-270 degrees is completed.**

Results

- **Testing showed the sluggishness only occurred during the initial start-up of the bearing and was worse when the bearing was commanded to azimuthal angles larger than the stopped position.**

PFM Azimuth Rotation Stickiness Recovery and Characterization

Impacts/Prognosis

- **Has delayed but not permanently prevented the collection of ADM data**
- **No solar calibrations have been conducted since they require the azimuth bearing to dwell for approximately 40 minutes at excessive angles. Worst case scenario for a stall an unrecoverable stall to occur.**
- **Performance seemed to improve as the bearing was operated for longer periods of time.**

Recovery/Characterization plan was completed in late March.

Increased A/D Converter Noise in April/May

Anomaly Description

- **CERES Production code calculates the standard deviation of the raw sensor counts for the spaceclamp (i.e. first 40 samples) in every data.**
- **Intended to monitor the baseline noise level of the instrument and catch corruption of our spaceclamp.**
- **On May 17th the standard deviation began exceeding a pre-determined threshold and approximately 5% of the data was flagged bad. By April 1st nearly 100% of the data was routinely being flagged bad.**
- **A review of the data showed the superposition of an approximately 9 hz signal on the radiometric data. This pattern corresponds roughly to activity of the Data Acquisition Assembly (DAA) microprocessor.**
- **Although the frequency characteristics of this signal remained relatively constant, the magnitude was very sensitive to temperature.**
- **On April 3rd, a large increase in the number of detector bridge balance resets was seen. This problem was traced to corruption of the DAA analog temperature parameters that were being used in the thermal control loop for the sensors.**

Increased A/D Converter Noise in April/May

Anomaly Description cont'd

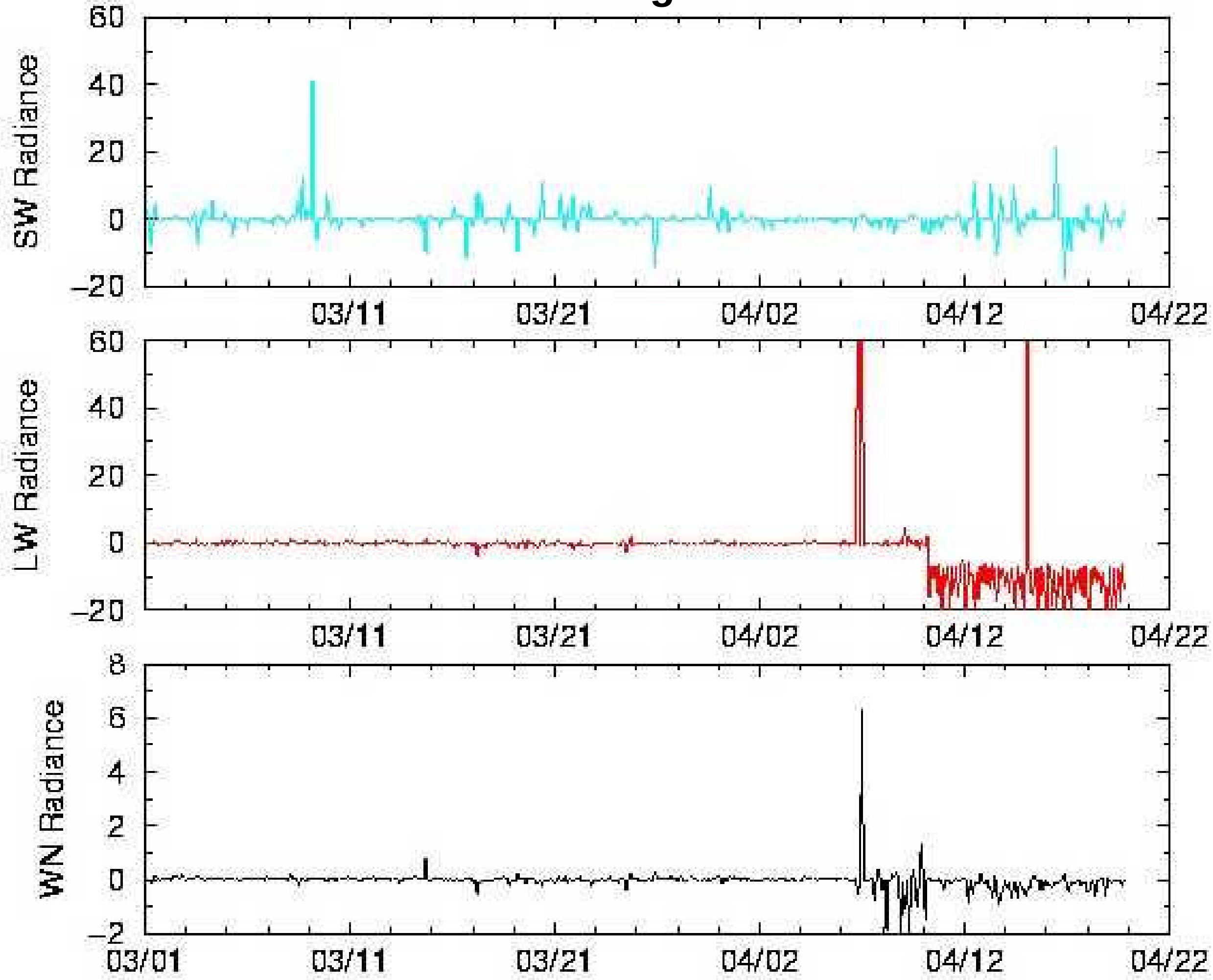
- On April 3rd, a large increase in the number of detector bridge balance resets. Primarily on the Total channel.
- Caused by corruption of the DAA analog temperature parameters being used in the thermal control loop for the sensors.
- On April 7th new bridge balance window parameters were defined to allow for larger drifts due to wandering thermal control.
- On April 10th thermal control turned off for the Total channel.
- Subsequently there have been approximately 6 diagnostic memory patches/loads implemented and the results analyzed.
- Analyses are on-going with daily communications between TRW, the TRMM Flight Ops Team, and NASA LaRC personnel.

Prognosis

- A unique cause/solution has not yet been determined. Suspicion lies with the failing 15volt converter. New results on an almost daily basis.
- Recovery of most of the April data is still considered possible.

Impact of Removing Thermal Control on the PFM Total Channel

Plots show relative radiance differences between FM1 and PFM measurements during intercalibrations



TRMM Edition 2 ERBE-Like Data Products

Norman Loeb, Richard Green, Kory Priestley

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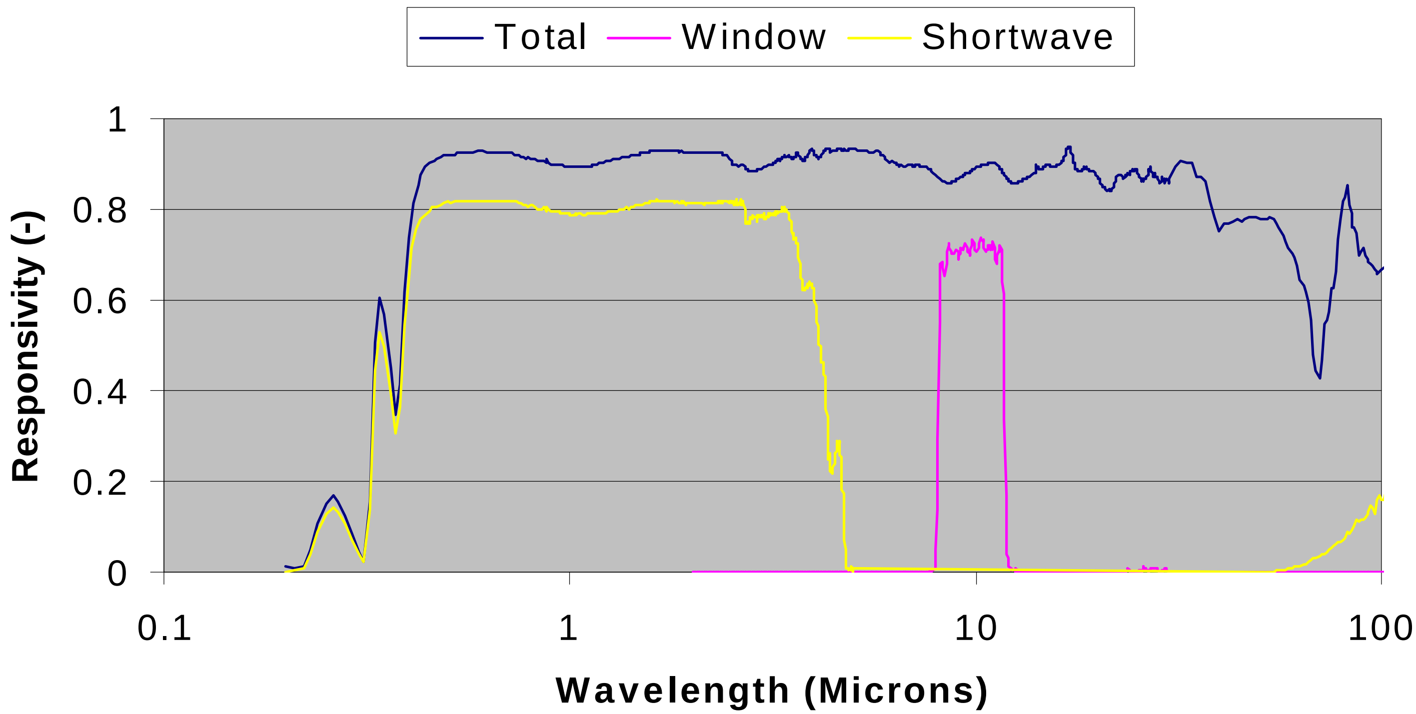
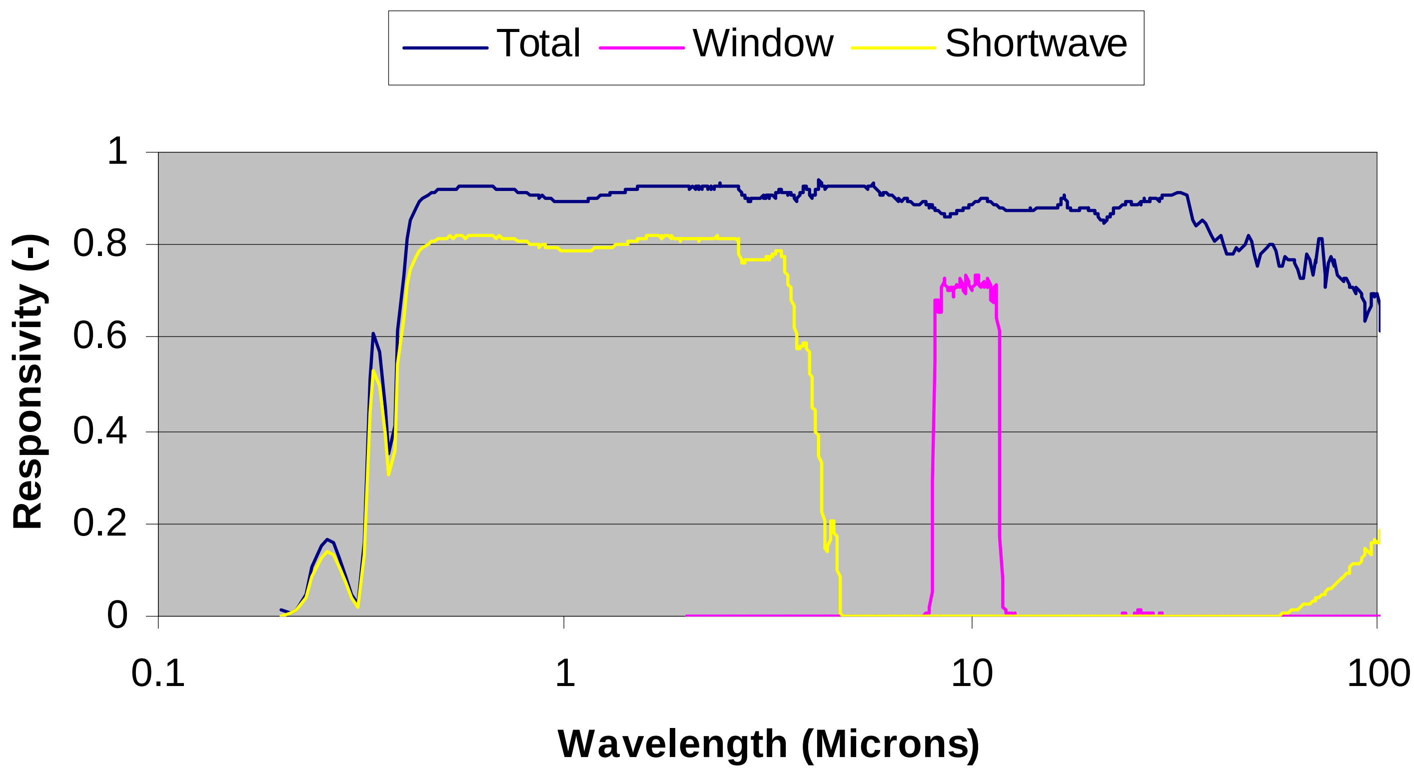
Preliminary CERES Proto Flight Model Edition 2 Spectral Response Function

(Presented in la Jolla,CA 12/99)



Final CERES Proto Flight Model Edition 2 Spectral Response Function



0.2 - 2.5 μm | 2.5 - >100 μm

SWRS | **Fourier Transform Spectrometer**

3-Channel Deep Convection Results

Relative (%) errors in unfiltering the Shortwave and Shortwave portion of the Total channels for June, July, and August 1998

	June	July	August	JJA
Edition 1	0.93	0.85	0.86	0.88
Edition 2	0.22	0.08	0.10	0.13
Δ(Ed1 – Ed2)	0.71	0.78	0.76	0.75

With this method we cannot distinguish between errors in the spectral response function and relative errors in the slope intercept spectral unfiltering method.

CERES vs ERBE Deep Convective Albedo Results

Results of estimating the Cloud reflectance at a solar zenith angle of 40-degrees. The relative uncertainty in each measurement is in parentheses.

	June	July	August	JJA
ERBE				.7154 (0.26%)
Edition 1	.7001 (.78%)	.7066 (.73%)	.7004 (.80%)	.7014 (.45%)
Edition 2	.7045 (.76%)	.7103 (.75%)	.7047 (.80%)	.7056 (.45%)

Edition 2 ES-8's yield a higher values of reflectance than Edition 1 by about 0.4% but are still approximately 1% below ERBE.